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TOOLS FOR MATERIAL DISINTEGRATION

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Abstract: Disintegration is one of the techniques used widely in primary and also in secondary industry. We can see disintegration in material preparation for producing of different parts from different material, but also as technique for waste modification or processing of production waste. For different technology and for different material we have to use also different machine types, but also when using same machine, we have to use different tool. The aim of this paper is to show variety of disintegration tool types, their usage, special geometry, design and geometry. We will describe what are the technical and technological parameters necessary for various types of material, in case if the material is fragile or tough. This technical, technological and geometrical parameters are also dependent on required output, what have to be size of outgoing fraction, if following technology needs exact dimensions or not. When the customer looks for disintegration machine, is necessary to answer a lot of questions which direct the final decision.

Keywords: disintegration, shredding, tool, material preparation, biomass preparation

1. INTRODUCTION

Different technologies in primary production, where the preparation of material is necessary, but also in the process of processing of secondary raw materials, require different devices. They are mainly the technology, where the homogenous mixture and reduction of used material are necessary, what are operations needful for example in briquettes and pellets from biomass production [1], [2], the treatment of waste materials in order to reduce the volume in storage. Shredding or disintegrating devices are useful for a wide range of applications and the processing of various materials. Currently, they are also used for example in disintegration of hydrate, as a potential energy source [3]. The design of whole apparatus for disintegration is different from the purpose and the type of processed material [6]. The devices for brittle, rigid and tough material are in principle different.

Another way of distinguishing can be the size of the input fraction of the material or semiproduct, which enters the equipment and the required fraction size. For bulk materials are the devices bigger and more robust, at the output of the device, there is achieved in this case larger fraction size, and generally not required exact maximum size of the individual disintegrated particles. In contrast to applications in which the input material size is few millimetres and on the output are obtained the particles size microns (for Nanotechnology are required even smaller particles).

2. TOOLS VARIABILITY FOR MATERIAL PROCESSING

In the case of brittle materials dividing is used completely different system than for tough and rigid material dividing. For brittle materials such as glass, much less force is sufficient to overcome the strength of the material. Also, the use of specialized tools, which is not a classic wedge tools for material cutting, but there is enough the simple roller on which the pins are located. When contacting the pin with glass, glass simply crack and this was is divided into the smaller parts. Little force is used, the device roller speed is variable, can be used lower but also higher rotational speed. With required higher production are used higher rotational speed of roller.

For cutting of tough materials such as straw or hay, it is necessary to use a high speed rotor, and its kinetic energy [5]. Required is a sharp cutting tool, small cutting tool thickness, which at the high speed chop up the material into the smaller pieces. In such cases, very often are used the bottom screen, which prevents premature fall of large particles outside the device workspace. The material is then maintained in the space, as long as its size is not smaller than the holes on screen. The result is a homogeneous fraction of a similar well-defined maximum size.

Cutting of hard materials can be realized, for example by the hammer mills that uses large kinetic energy of tools. They are located on the rotary pins, with high speed impinge on crushed material, which is by high kinetic energy divided up into smaller particles.

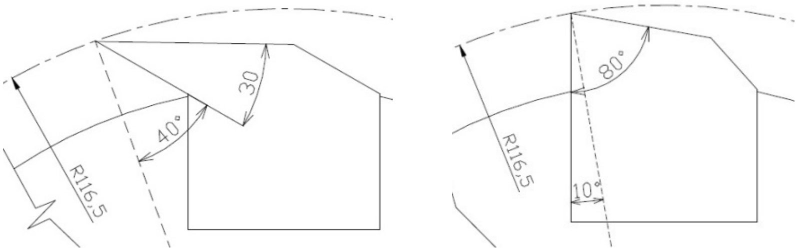

Figure 1: Illustration of usable disintegrative tools variability

As in previous, there is possible to use screens located at the bottom of the device in order to achieve the desired output fraction size.

The classical two-rotors or single-rotors shredding machines are used to divide large spectra of material types. These are mostly low-speed shredders. Material disintegration is occur always between shredding wedge and the fixed part of the machine or between two shredding wedges. There are used processes such as cutting, breaking, splitting, and others. By adjusting of disintegrating workspace, disintegration tools size, shape and geometry, can be customized the device for different materials processing and to optimize the process using the lowest necessary device load to use the drive with the smallest possible input or maximize the amount of processed material.

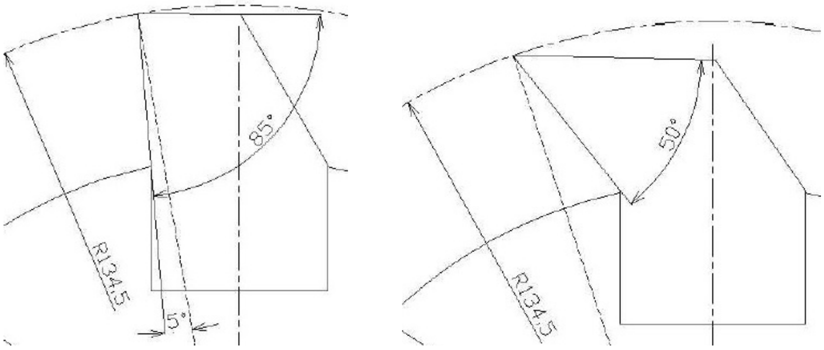

Figure 2: Variability of usable disintegrative tools on the same device

On the Figure 1 and Figure 2 it can be seen different disintegrating wedges geometries. Figure 1 shows a small tool with limit geometry. On the left side is the tool with cutting-edge side rake $\gamma =$ 40°. This is the maximum cutting-edge side rake, because with the higher angle the wedge would be weakened and the wedge could by break. This tool is in operation penetrating into the material, smoother and easier to overcome cross-section of the processed material. It is suitable for ductile and tough materials at lower power claims. On the right side is the wedge that is completely flat, so that the material does not cut the tip, but by surface and by wedge sides crushing the material. There are higher requirements for power load to overcome the strength of the material with this wedge. It is preferable especially for fragile materials.

On the Figure 2 are illustrated wedges, which have raised the functional part, so on the one time they are able to cover a larger piece of material. The advantage is thus the greater productivity of this tools. By contrast, the main disadvantage of this tool is, required higher drive power input to be able process more material on one time.

3. MINIMAL LOAD OBTAINED BY SETTING CHANGE

In the previous papers for this problem have been reported dependence of two variables, so we observed for example, how are changing the size of the necessary disintegrating forces with change of some important parameter. The significance of the parameters was evaluated on the basis of prepared and evaluated experiments in which they were reviewed four selected parameters on which we supposed that they will have biggest influence to on reviewed disintegration force size, or derived torque.

Selected are following reviewed parameters:

- Factor A: cutting-edge side rake size γ on disintegrative wedge;
- Factor B: cutting clearance angle size α on disintegrative wedge;
- Factor C: disintegrative device rotors rotation frequency n;
- Factor D: disintegrative surface area S of disintegrating material.

By experiment evaluation, we came to the results what can be seen on scatter diagram (Figure 3). From this we can see that the biggest significance has the effect of factor D with a point value of 67 (disintegrative surface area S of disintegrating material). Followed by the effect of factor A with a point value of -62 (cutting-edge side rake size γ on disintegrative wedge). An significant effect is even indicated by interaction of factor A and D with point value 19 (S, γ). The effects of others factors and their interactions appears as not significant.

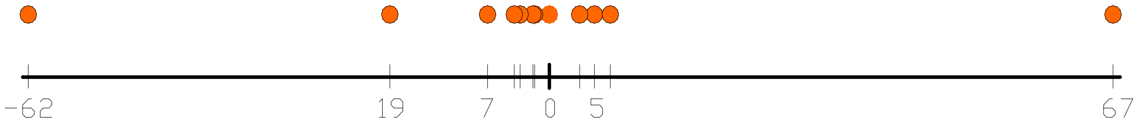

Figure 3: Scatter diagram with experiment results

The result of extended experiment is modified mathematical model (1, 2), designed to calculate a more accurate determine of the necessary disintegrating forces.

Based on the proposed experiment plan, was among of others parameters measured also face angle γ change impact on torque moment value, which is necessary to material samples disintegration. Following the measurement results, there was modified the basic form of mathematic model describing the disintegration process to the following form [7]:

$$M_k = \tau \cdot R \cdot S_m \cdot (1 - \tan \gamma) \tag{1}$$

$$F_{D1} = \tau \cdot S_m \cdot (1 - \tan \gamma) \tag{2}$$

where: F_{D1} – disintegrative force for single wedge (N), Mk – torque moment (Nm), τ – shear strength of material (MPa), R – disintegrative disk radius (mm), S_m – disintegrative surface area (mm^2), γ – cutting-edge side rake (°).

Mentioned mathematical model was created based on experimental measurement which take into account the disintegrative wedge geometry (Figure 2, cutting-edge side rake size γ and cutting clearance α), rotor rotating frequency n and disintegrating material section surface area S_m, which take into account width b and height h of disintegrative wedge and thickness of processed material h_m.

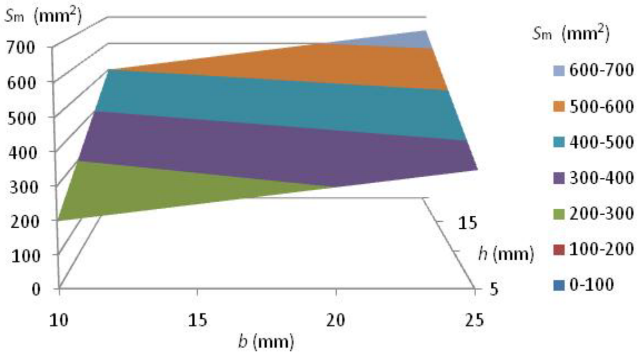

Figure 4: Value of material cross-section area for different disintegrative tool height and width

Based on experiment results and final mathematic formula (1, 2) we could prepare three dimensional dependences of several factors, for better illustration of results. On the Figure 5, Figure 6 and Figure 7 we can see development of required disintegrative force size, with change of basic parameters. We choose two basic parameters, which also comes from our experiment as significant. They are size of cutting-edge side rake on the tool and surface area of material cross section, which have to be overcome.

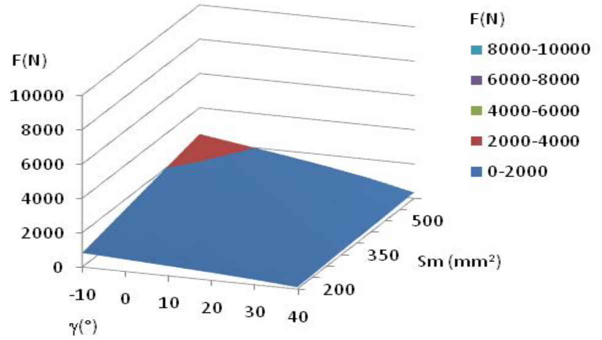

Figure 5: Value of disintegrative force with cutting-edge side rake and tool cross-section change for material shear strength 3,5 MPa

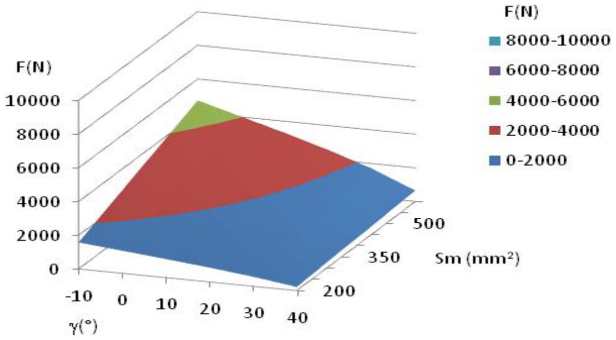

Figure 6: Value of disintegrative force with cutting-edge side rake and tool cross-section change for material shear strength 6,7 MPa

If we look at the method of calculation of the surface area S_m (3), we see that largely depends on the dimensions of a disintegrating tool and also on the thickness of the disintegrated parts of the material. As mentioned above, the material cross-section has been evaluated in realized experiment as most significant, what does make a sense in relation to basic of single process. The cross-section size of the shredded material is also basically depended from dimensions and geometry of disintegrative wedge. They are firstly height and width of used disintegrative wedge. Another significant parameter which is showed in illustrated 3D dependences is cutting-edge side rake γ. This parameter was evaluated in an experiment as the second ranked most significant.

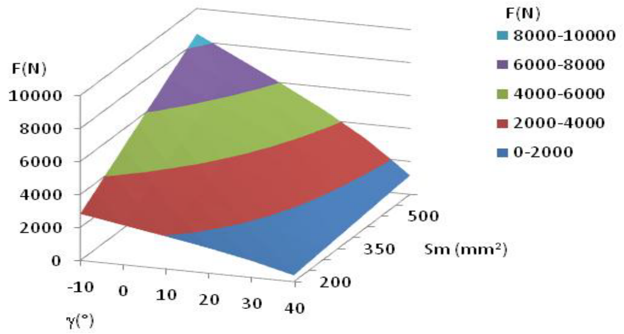

Figure 7: Value of disintegrative force with cutting-edge side rake and tool cross-section change for material shear strength 12 MPa

For calculation of material disintegrative surface area, which have to be overcome by disintegrative wedge, we should use following formula:

$$S_m = h_m (2 \cdot h + b) \tag{3}$$

where: S_m – material disintegrative surface area, which have to be overcome (mm^2), h_m – material thickness (mm), h – wedge height (mm), b – wedge width (mm).

This mathematic formula (3) was also established on the basis of the experiment mentioned above [4], [7]. From formula (3) we see that the cross-sectional size is growing two times faster with disintegrating wedge height than with wedge width. By increasing the wedge height, the disintegrative surface will rise doubly. Therefore, it is preferable to reduce the height of the wedge, thereby reducing the load of the machine and also required drive power input. In this way, we reduce also device productivity, since it removes less material with smaller disintegrating device wedge. This fact can be seen in the 3D chart, which shows the dependence of the size of material disintegrative surface from wedge height and also its width. The value of surface area S_m has an effect on size of necessary disintegration force F. This dependency can be seen in Figure 5, Figure 6 and Figure 7.

Following figures (Figure 5, Figure 6, Figure 7) are 3D graphs in which we can watch the size of a disintegrating force depending on the values of surface area S_m and cutting-edge side rake γ for three different materials, of which shear strength is 3,5 MPa , 6,7 MPa and 12 MPa, to see how the disintegrative forces develop for different parameters. Range of shear strength is useful for wood materials, where the shear strength in direction of wood fibre in the range of 6-19 MPa and in direction across the fibres the range is 3-8 MPa.

If we compare all of the three shown dependencies we found, that the best way to reduce the required disintegrating force for shredding of desired material, is to work with tool cutting-edge side rake γ, where the desired effect is achieved faster already with minor change. In case of change of material disintegrative surface area S_m need greater change in this parameter to achieve the same changes. We can see the slope angle of the curve in the chart described images.

In a variant describing the situation with a tensile shear $\tau =$ 12MPa this is more noticeable and it results also from the mathematical model, which was based on the performed experiment and is verified by additional experiments. By making a series of similar charts we can assist in determining the necessary indicative of structural and technological parameters when the device is designing. However it is necessary the preparation of such charts for wide range of materials with different shear strength.

4. CONCLUSION

3D charts served clearer and more precise information on how we can affect a disintegrating force size needed to overcome the shredded material strength. Classical x-y dependence of two parameters can show a simple one parameter influence on the development of a disintegrating force, but does not allow comparison and selection the most effective way to reduce this power.

The target of all shredding machine manufacturers is to reduce disintegrating forces and thus reduce the required drive power and the cost of operating for these devices. As described above, it is more effective if we change the tool cutting-edge side rake, how we should change the width and height of a disintegrating wedge. Disintegrating forces reducing we can reach faster and in bigger size by changing of tool cutting-edge side rake. In case we get the tool design limits for cutting-edge side rake angle, it is possible to combine this change with the change of width and height of the disintegrative wedge.

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